FUNDAMENTALS OF HYDROACOUSTICS

PROPERTIES OF SOUND

OVERVIEW

Recognize the three basic elements necessary for the production of sound and which one controls the speed of sound.

Identify the various properties of sound waves.
Define energy loss or spreading loss as it pertains to sound waves.

Define Doppler effect, and recognize how it effects the pitch and frequency of sound.

OUTLINE

Sound production

Sound waves

Energy loss

Doppler

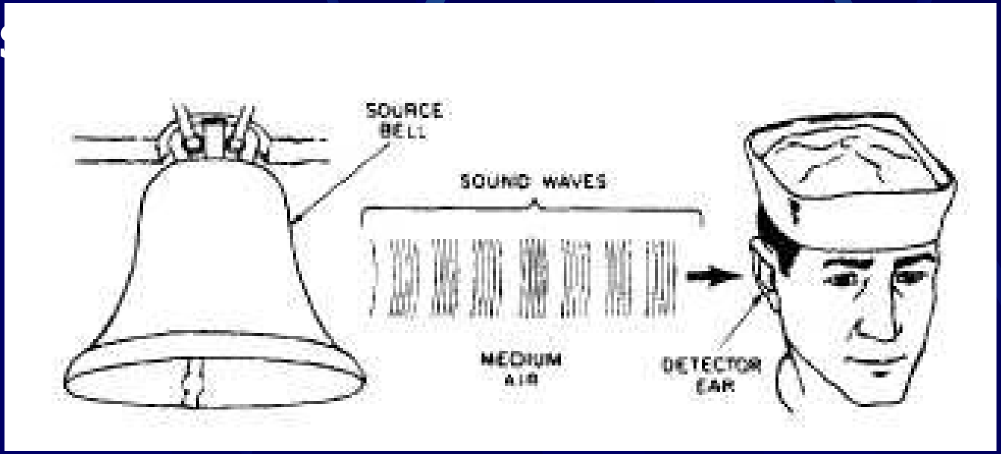
Learning Objective:
Recognize the three basic elements necessary for the production of sound and which one controls the speed of sound

SOUND PRODUCTION

Sound is the physical cause of hearing. Anything that you hear is a sound. However, before sound can be produced, three basic elements must be present: **SOUND SOURCE**, a **MEDIUM**, and a **DETECTOR.**

Source

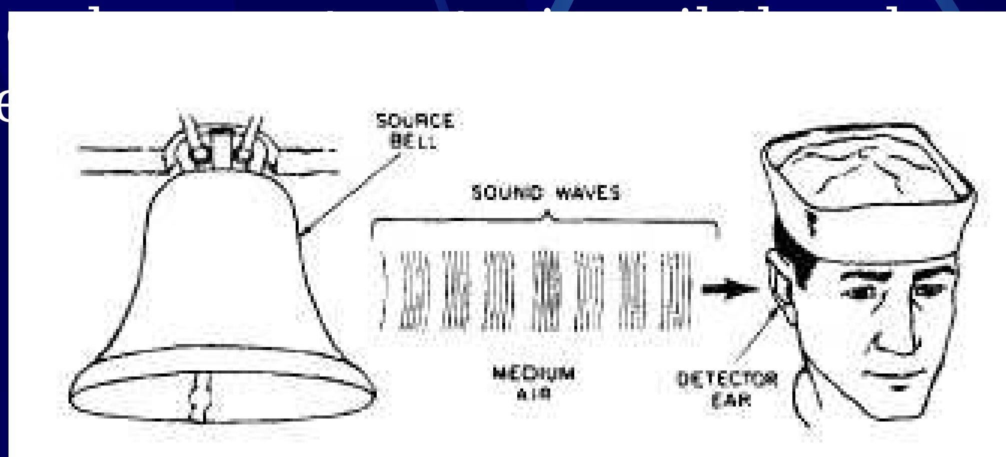
Any object that vibrates or disturbs the medium around it may become a s



Bells, radio speaker diaphragms, and stringed instruments are familiar sound sources. The sound source is the initial requirement in the production of

Medium

The second element needed to produce sound, the medium, is the element that carries the sound. Your alarm clock goes off and you are awakened by the sound. The sound reaches your ears through the air in your bedroom. Air is a medium. Particles in the air carry the sound to you. Noises or sound are also heard underwater, because particles in water carry sound. A more dense medium than that of air or water is that of steel. A person can detect an approaching train far faster by pressing his ... tanding alongside the ...



The medium is the controller of sound. It controls how far and how fast sound travels. Sound travels faster, farther, and with more ease through mediums of high elasticity and density. In general, solids are better transmitters of sound than either

SPEED OF SOUND

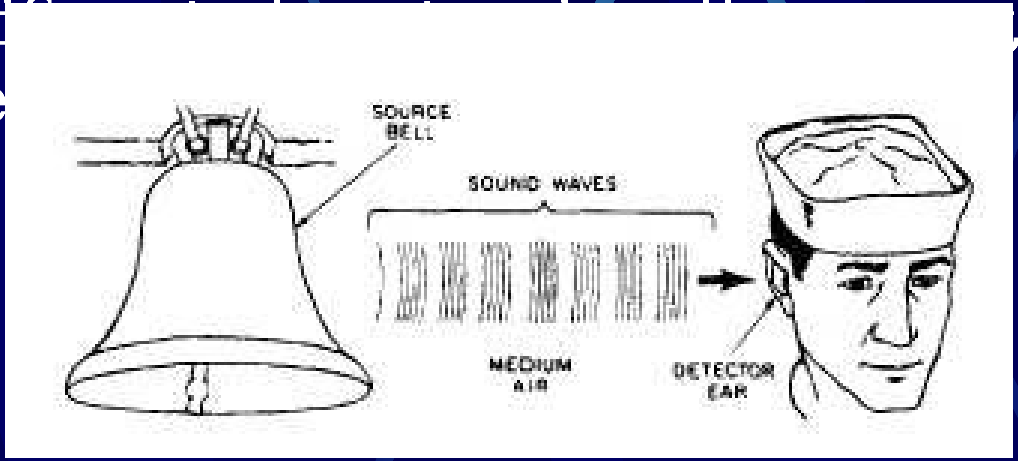
The speed of sound in air is approximately 331.5 m/sec at 0°C. Sound speed lowers at lower temperatures and increases at higher temperatures. Sound speed increases at a rate of approximately 0.6 m/sec for every 1°C increase in temperature.

The speed of sound in water is about 4 times greater than the speed of sound in air. Seawater is more dense than fresh water; therefore, at the same temperature, the speed of sound in sea will be slightly greater than the speed of sound in fresh water.

In steel, sound speed is about 15 times greater than in air. Sound travels at approximately 5,200 m/sec through a thin steel rod.

Detector

A detector acts as a receiver of sound. The detector permits us to tell whether sound has been produced. Sound travels in waves that move radially (360 degrees) from their source, and only a small part of a wave’s energy reaches a detector. Therefore, detectors often contain ampli ... thereby permitting re



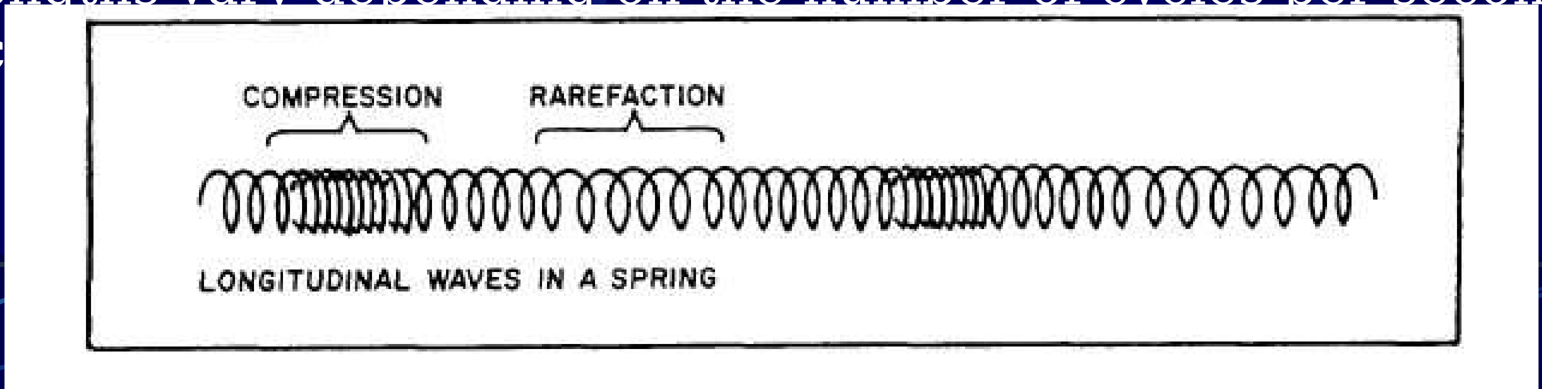
Learning Objective:
Identify the various properties of sound waves.

SOUND WAVES

Sound travels in the form of waves. Sound waves are brought about by vibrations within a medium. The vibrations produce compressions (pressure increases) and rarefactions (pressure decreases) that impact the particles within the medium. The particles do not physically move, but the energy is transferred from particle to particle. This is how the sound travels. A single sound wave consists of one compression and one rarefaction.

Wavelength

The length of a sound wave is the distance between any two successive compressions or rare fractions. The figure below illustrates a longitudinal wave with its compressions and rarefractions. One complete wavelength is called a cycle. Wavelengths vary depending on the number of cycles per second produc



Frequency

The number of cycles per second (cps) is a measure of a sound’s frequency. The higher the frequency, the shorter the wavelengths, and vice versa

Frequencies are measured in the Hertz system, 1 hertz (Hz) is equal to 1 cycle per second (cps). Frequencies of 1000 Hz or more are measured in kilohertz (kHz). The average human hears sounds between 20 Hz and 15 kHz, while sounds below 20 Hz and above 15 kHz are normally beyond the human range of hearing.

Pitch

The pitch of a sound depends on the frequency of the sound as received at a detector. The human ear detects sounds and classifies them based on the sound quality. Some sounds are harsh, while others are pleasant. Pitch is a subjective quality dependent on the receiver.

Intensity and Loudness

Intensity and loudness are often mistaken as having the same meaning. Although related, they are not the same. Intensity is a measure of a sound's energy, while loudness is the effect on the detector. If sound intensity is increased, the loudness is increased but not in direct proportion. To double the loudness of sound requires about a tenfold increase in the sound's intensity. Sound intensity is measured in decibels (dB). A decibel is the unit used to express relative power (intensity) differences between acoustic signals (sounds). Decibel levels are assigned based on a sound's intensity compared to an established standard. Some common intensity levels are as follows: a whisper, 10 to 20 dB; heavy street traffic, 70 to 80 dB; thunder, 110 dB.

Learning Objective:

Define energy loss or spreading loss as it pertains

ENERGY LOSS

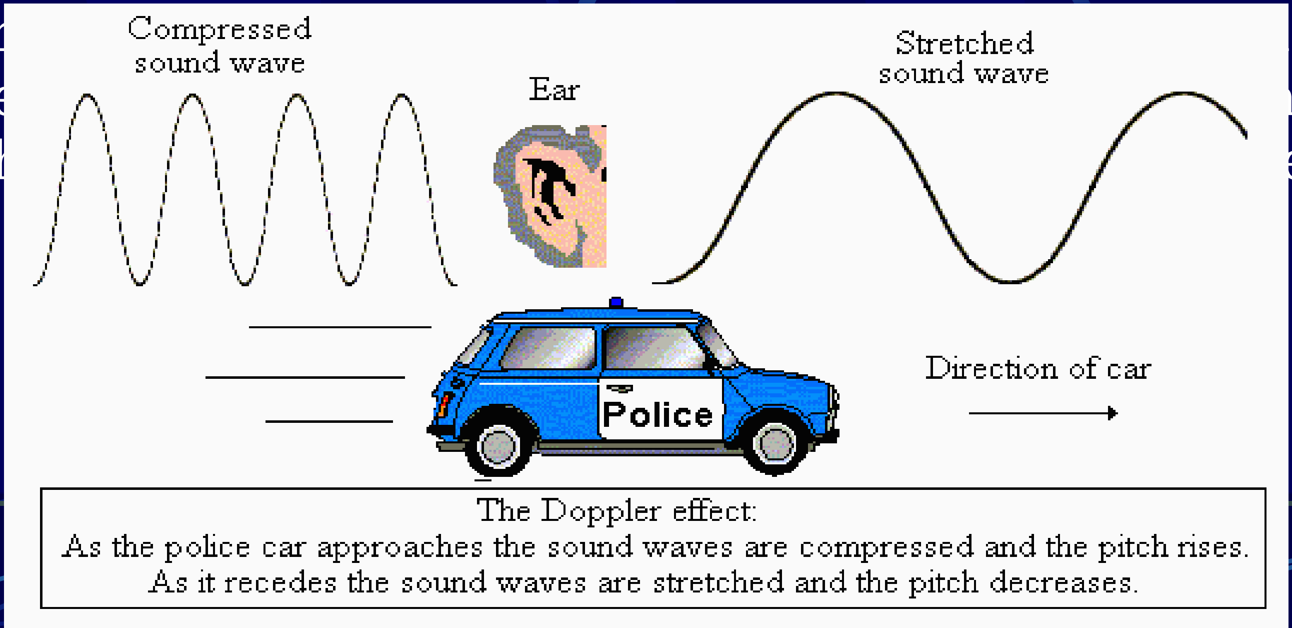
As a sound wave moves away from its source, it spreads out. The energy within the wave decreases as the wave spreads through an increasingly large area. Thus, the wave energy per unit area decreases as the distance from the sound source increases. This loss of energy due to distance is known as spreading loss.

Learning Objective:

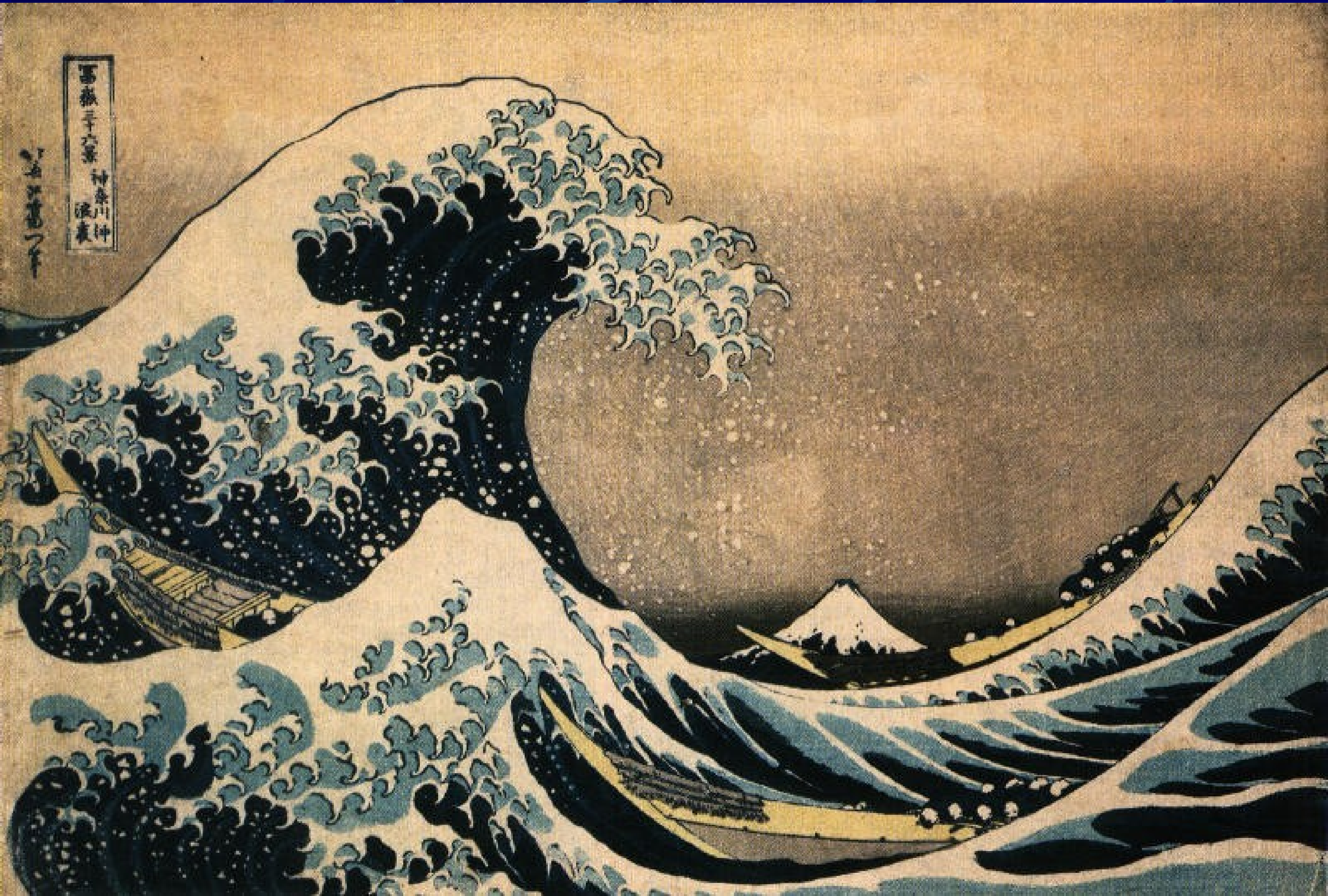
Define Doppler effect, and recognize how it effects the pitch and frequency of sound.

DOPPLER

The Doppler effect is the apparent change in a sound due to motion. It is a change in pitch (a detector variable) without a frequency change occurring (a sound source variable). The change in pitch is brought about by the relative motion of a sound source and a detector. For example, we hear the whistle of an approaching train. The frequency of the whistle does not change as the train approaches, but our ears detect an increase in the pitch. The increase in pitch is caused by the compression of sound waves. The train acts to "push" the sound waves toward us. The sound waves arrive at a faster rate than they would if the train was not moving. Then, as the train goes by, the sound waves arrive at a much slower rate. The tr ... us. The sound wave ... s the train moves farth ... e of lower pitch.



SOUND PROPAGATION IN SEAWATER



OVERVIEW

Define sound velocity, and describe the effect of temperature, pressure, and salinity on sound.

Explain why sound propagates along more or less curved paths, and describe the five basic sound ray patterns and their attendant temperature and sound velocity profiles.

Differentiate between active and passive sonar, define the two modes of active sonar search, and describe the propagation paths used with each mode.

Define and differentiate between the elements used in the active and passive sonar equations.

OUTLINE

Sound velocity

Active and passive sonar

Learning Objective:
Define sound velocity, and describe the effect of temperature, pressure, and salinity on sound.

SOUND PROPAGATION IN SEAWATER

In physics, the word *propagate* means to cause (e.g., a wave) to move through a medium. In our study of sound, we learned that the medium controls sound. In this lesson, we will look at the effect of the sea on sound waves as they move through it.

SOUND VELOCITY

Sound velocity takes into account the speed and direction of sound rays. The direction or path that sound energy takes as it moves through the water is primarily a function of sound speed.

Sound Speed

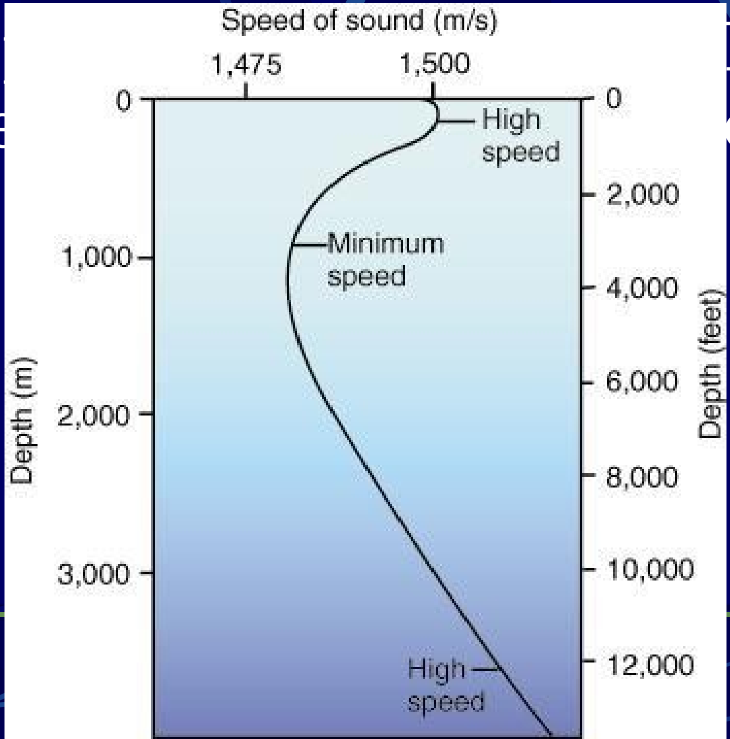
The speed of sound in the sea is a function of water temperature, pressure, and salinity. Of these three variables, temperature is the most important. It is the primary controller of sound speed, and therefore direction, in the upper 300 meters (1,000 feet) of seawater. In general, sound speed increases 2.4 m/sec for every 1°C increase in temperature.

The effect of pressure on sound speed is a function of depth. The greater the depth, the greater the pressure; the greater the pressure, the greater the sound speed. Sound speed increases approximately 1.7 m/sec per 100 meters of depth. Pressure is the dominant sound speed controller below 300 meters, because below 300 meters, the temperature is relatively constant.

The effect of salinity on sound speed is slight in the open sea, because salinity values are pretty much constant. The affect of salinity on sound speed is greatest where there is a significant influx of fresh water or where surface evaporation creates high salinity. A

SOUND-VELOCITY PROFILE (SVP)

A sound-velocity profile is simply a graphic representation of speed versus depth. Sound-velocity profiles are constructed from sound-speed nomograms based on temperature, depth, and salinity. They can also be constructed from bathythermograph soundings by computing the sound speed at significant and mandatory depths. An SVP provides surface sound speed, depth of maximum sound s[illegible]h), and layers where sound trave[illegible]cts and sound channels).



Sonic-Layer Depth (SLD)

The sonic-layer depth is the depth of maximum sound speed. In most instances, the SLD is the same as the mixed-layer depth (MLD). The SLD can be determined from a BT trace. A negative-temper-ature gradient (temperature decreasing with depth), within certain limits, compensates for an increase in sound speed with depth due to pressure; this results in a constant sound speed with depth. These gradient limits per 30 meters of depth are as follows:

l 0.1°C per 30 meters in water 4.4°C

0.17°C per 30 meters in water 12.8°C

0.22°C per 30 meters in water 18.3°C

Temperature gradients that are more negative than those listed (temperature decreases at a greater rate) result in decreasing sound speed with depth. Gradients that are more positive result in increasing sound speed with depth. Of course, sound speed increases with depth when the water temperature is constant because of the increasing pressure.

The SLD can be determined from a BT trace by considering the following criteria:

1. If the maximum temperature is at the surface, and the gradient is more negative than the limits listed, the SLD is zero. It's at the surface.

2. If the BT trace is isothermal or has a slight negative gradient (less than the stated limits) and then becomes more negative, the SLD is at the bottom of the isothermal or slightly negative gradient layer.

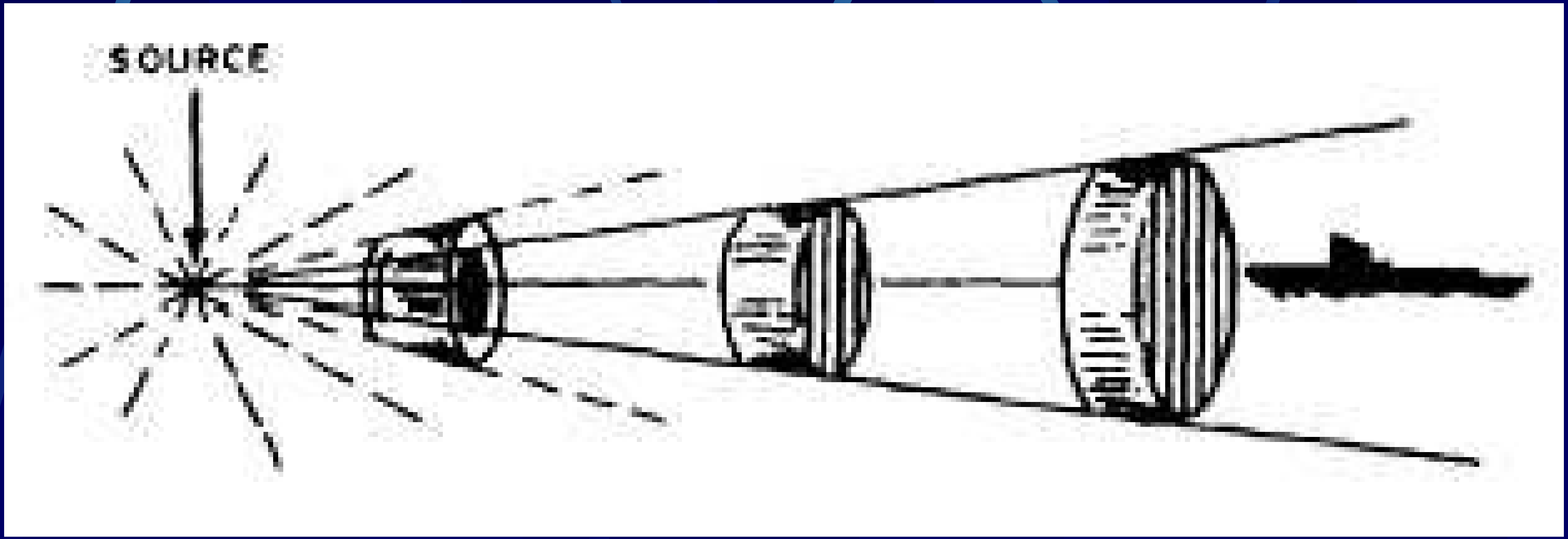
3. If the maximum temperature occurs at a depth other than the surface, this is the SLD, unless the gradient below depth of the

When predicting sonar ranges, in-layer and below-layer ranges are computed. The term while below-layer pertains to the layer beneath the SLD.

Learning Objective:
Explain why sound propagates along more or less curved paths, and describe the five basic sound ray patterns and their attendant temperature and

Sound Paths

As sound energy leaves a sound source it travels in waves. The sound waves expand as they move away from the source. A sound wave's path of travel is dependent on its speed and any matter in its path. Sound, like light, is refracted, reflected, and scattered.



Outgoing ping showing shape of beam pattern and divergence of sound rays.

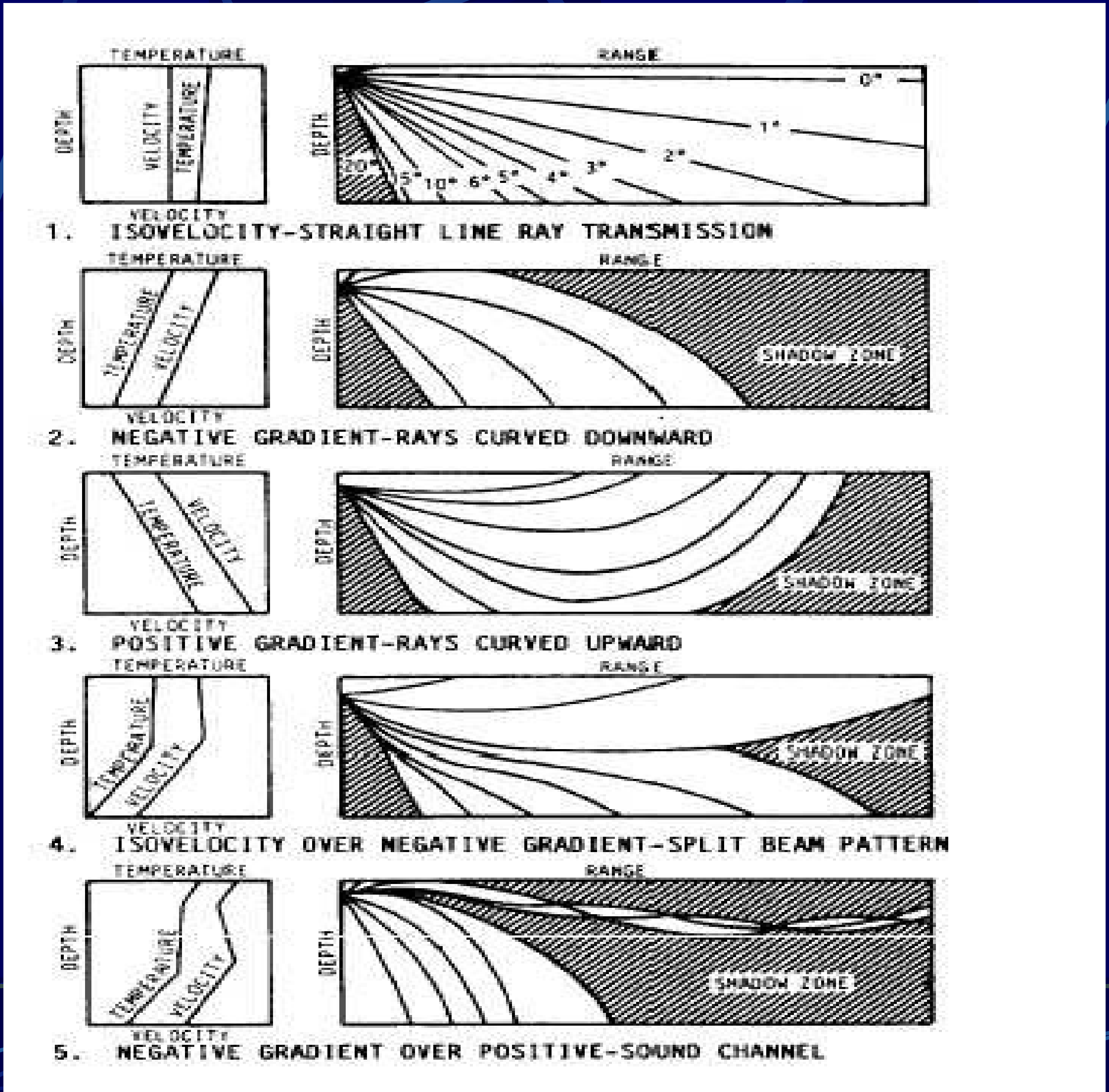
REFRACTION

As a sound wave moves through the sea, it travels along a curved path. The path is curved, because sound speed varies along the wave front. Sound waves bend (are refracted) in the direction of the slower sound speeds. This is the fundamental principle of sonar-range prediction and is derived from Snell's law. Snell's law states that a sound ray propagating through a region with one sound speed will change direction (be refracted) on entering a region having a different sound speed.

The degree of refraction is proportional to the sound-speed gradient. The greater the change in speed over a given distance or depth, the greater the refraction. The gradient is a function of speed versus depth or distance. For example, in a layer of water where sound speed decreases rapidly with depth (a strong negative-velocity gradient), sound waves bend sharply downward. Sound rays refract upward if sound speed increases with depth (a positive-velocity gradient).

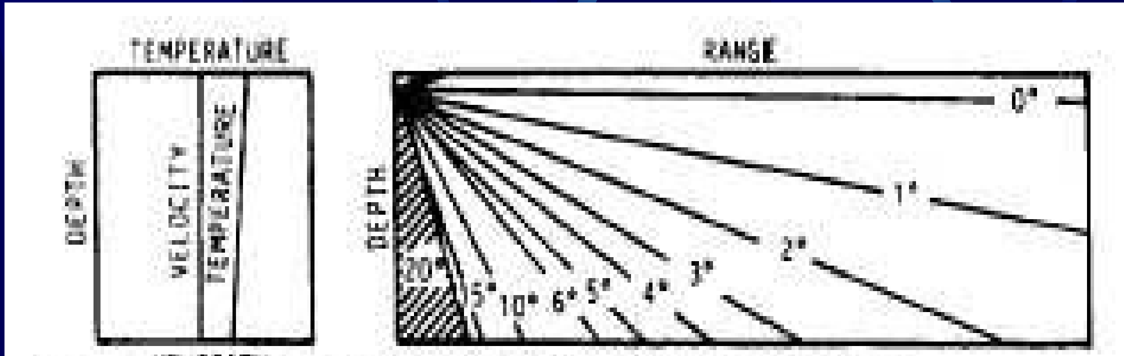
5 BASIC SOUND TRANSMISSION PATTERS

The BT sounding and SVP which bring about these paths accompany



Straight Rays (ISOVELOCITY)

Sound rays travel in straight lines only where the speed is everywhere constant (isovelocity); no change in velocity with depth. Straight sound rays occur when the temperature profile is slightly negative (a decrease of about 1°C per 30 meters of depth). Long sonar ranges are possible when this type of profile exists.



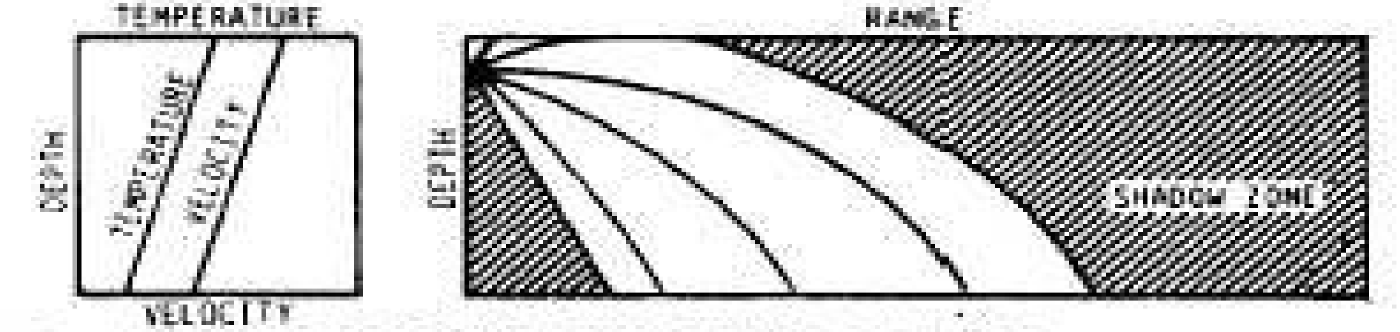
1. ISOVELOCITY-STRAIGHT LINE RAY TRANSMISSION

Rays Curved Downward (NEGATIVE GRADIENT)

A negative-temperature gradient (temperature decreasing with depth) produces a negative-velocity gradient. The sound rays leave the sonar and are bent downward, thereby limiting sonars to very short ranges. For example, a decrease in temperature of .56°C in the first 10 meters causes the sound beam to miss a shallow target at a range of 1 km.

This is a common occurrence in the near-surface layer. Beyond the range of the downward bending sound rays, sound intensity is negligible.

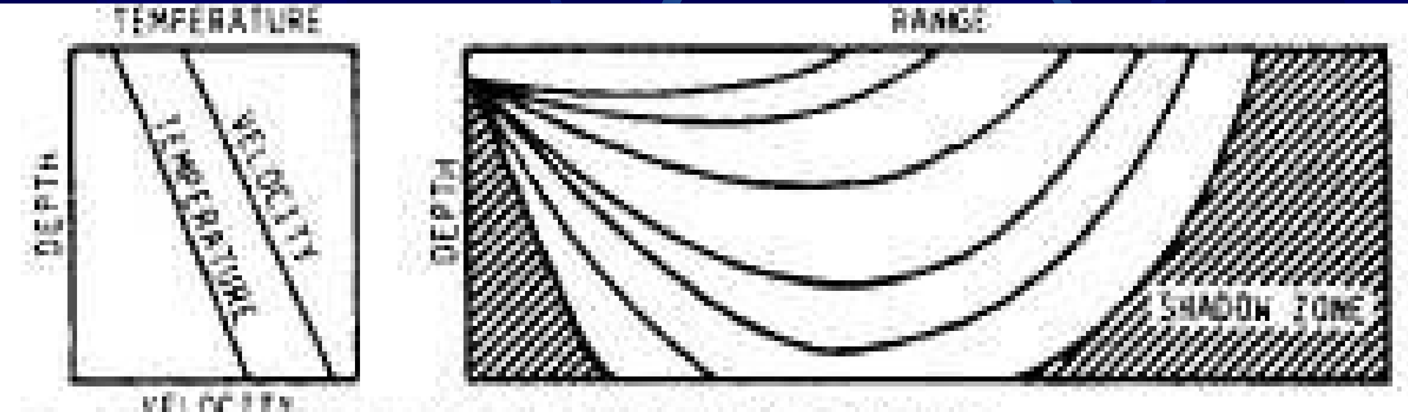
This area is known as a shadow zone.



2. NEGATIVE GRADIENT-RAYS CURVED DOWNWARD

Rays Curved Upward (POSITIVE GRATIENT)

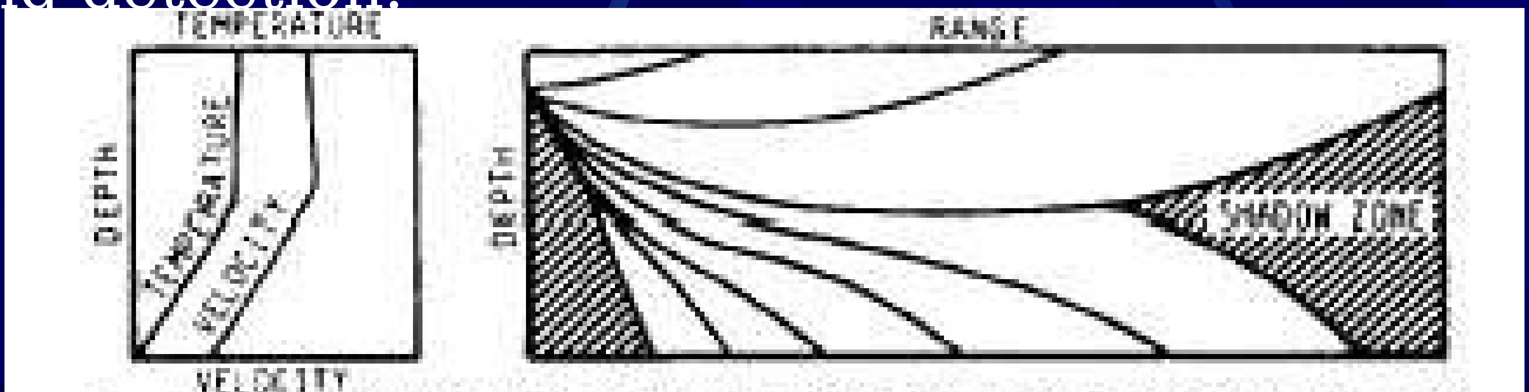
A positive-temperature gradient causes sound speed to increase with increasing depth, and sound rays to refract upward. Longer ranges are attained with this type gradient, especially if the sea is relatively smooth. As the rays bend upward and strike the sea surface, they are repeatedly reflected to longer ranges.



3. POSITIVE GRADIENT-RAYS CURVED UPWARD

Split-beam Pattern (ISOVELOCITY OVER NEGATIVE)

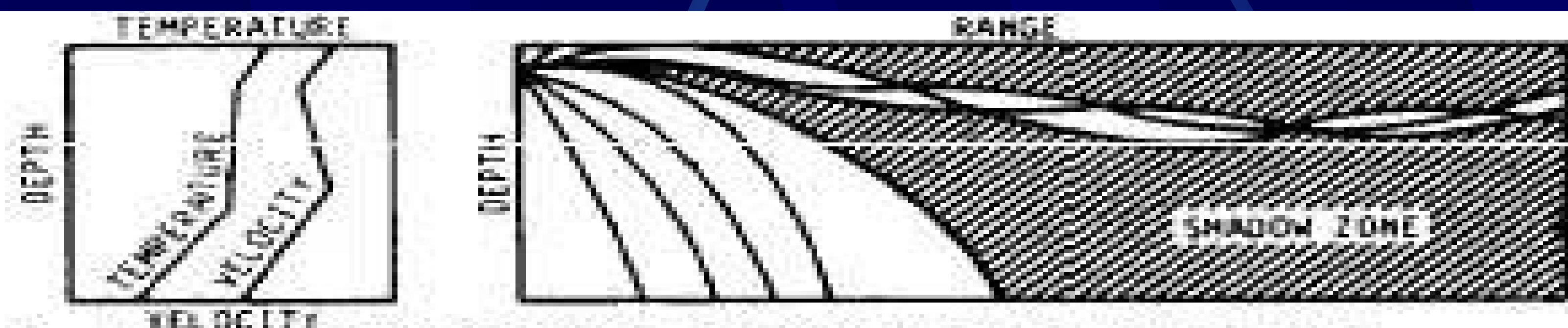
A split-beam pattern occurs when the temperature gradient in the near-surface layer is isothermal, and negative below. Sound rays from a sonar split at the depth of the gradient change. Part of the sound rays are refracted upward toward the surface, and part are refracted downward toward the bottom. At the point where the rays split, a shadow zone exists. A submarine operating at the split depth improves its chances of avoiding detection.



4. ISOVELOCITY OVER NEGATIVE GRADIENT-SPLIT BEAM PATTERN

Sound Channel (NEGATIVE OVER POSITIVE)

A sound channel occurs when a negative-velocity gradient overlies an isovelocity or positive-velocity gradient. The depth where the velocity gradient changes from negative to positive is the axis of the sound channel. The axis is the level of minimum sound speed. The sound rays on both sides of the axis travel faster than the rays in the center. And since sound refracts toward slower sound speeds, the faster rays are continually refracted toward the axis.



5. NEGATIVE GRADIENT OVER POSITIVE-SOUND CHANNEL

REFLECTION

Sound waves that strike solid surfaces have all or a portion of their energy redirected or absorbed. The surface or object struck determines if the sound energy is reflected, scattered, or absorbed.

Reflected sound energy can be good or bad. The type or quality of reflected sound is dependent on the surface from which the sound bounces. For example, a smooth hard surface is a good reflector. Sound waves bounce off such surfaces specularly (like a mirror) and lose little of their energy. On the other hand, an irregular hard surface is not a good reflector. The sound waves are reflected in many different directions and lose a good deal of their energy. This type of inflective energy loss is known as scattering.
Sound energy in the sea is scattered by the sea surface, sea floor, and suspended matter. Because the sea surface is rarely smooth, it is more apt to scatter sound than to reflect it specularly. A rough or rocky bottom also disperses or scatters sound energy.

In contrast to these rough surfaces, a smooth rock ocean bottom is perhaps the best reflector of sound in the sea. A smooth sand bottom also reflects sound very effectively. The sea surface, if it is calm, is

REVERBERATION

Reverberation is noise or interference at a sonar receiver, which makes target detection very difficult. This interference is caused by scattered sound energy being reflected back to the sonar receiver. There are three types of reverberation: surface, volume, and bottom.

Surface Reverberation

Surface reverberation is a product of surface wave action. At short ranges, surface scattering increases with wind speeds between 7 and 18 knots. Above 18 knots, a further increase in the surface-reverberation level is prevented by a sound screen of entrapped air bubbles. The air bubbles form near the surface and are caused by the wave action.

Volume Reverberation

Volume reverberation is caused by scatterers or reflectors in the water such as fish, marine organisms, suspended solids, and bubbles. Volume scatterers are not uniformly distributed in depth, but tend to be concentrated in a diffuse layer known as the deep-scattering layer

The deep-scattering layer is found in tropical waters at depths between 100 and 400 fathoms

The intensity of the scattering is a function of sonar frequency (some sonar frequencies are affected to a greater degree than others) and the density of the organisms in the layer. In the Northern Hemisphere, the maximum volume reverberation occurs in March and the

Bottom Reverberation

Bottom composition and roughness govern the degree of reverberation that contributes to the masking of target echoes. In theory, the amount of bottom reverberation is directly related to the roughness and com-position of the sea floor. However, the problem of bottom reverberation is a bit more complicated. Scientists consider the ocean floor to be a two-dimensional volumetric scattering surface. In other words, sound is not only reflected off the sea floor but also from formations of rock beneath the sea floor.

Also, bottom roughness can be slight or great, and the wavelength component of the reflected sound can range from microns to miles. The following conclusions were drawn from a Russian study (Jitkovskey and Volovova, 1965): (1) When bottom roughness is large compared to the wavelength of the sound being bounced off it, the amount of sound energy scattered back to the receiver (back scattering) is independent of frequency and (2) when the bottom roughness is small compared to the wavelength of the transmitted sound, scattering strength expands with increasing frequency.

Another problem created at the ocean bottom is one of absorption. When the bottom is composed of soft mud, sound energy is absorbed. Absorption also occurs as sound propagates through the

ATTENUATION

Attenuation is the energy loss that occurs in propagated sound waves due to scattering and absorption.

Learning Objective: Differentiate between active and passive sonar; define the modes of active-sonar search; and describe the propagation paths used

ACTIVE AND PASSIVE SONAR

Sonar (Sound Navigation and Ranging) was originally designed to assist surface ships to navigate in bad weather. Later, it was employed on submarines, and today it is our primary means of locating submarines. There are two types of sonar searches: active and passive. An active sonar employs a transmitter to send out sound pulses and a receiver to record returning echoes. A passive sonar listens for sounds generated by other ships and submarines.

Active Sonar

Active-sonar search is classified into two modes: shallow-water transmissions and deep-water transmissions. Theoretically, the essential difference between shallow- and deep-water transmissions is the interference effects produced by the multiple reflections of sound in shallow water.

Shallow water is classified as water less than 100 fathoms—that is, water over a continental shelf. Deep water is classified as water 1,000 fathoms or deeper. Water between 100 and 1,000 fathoms deep is most common over continental slopes. It is not considered overly important in active sonar operations because it exists in such a small portion of the world's oceans.

SHALLOW-WATER TRANSMISSIONS

Shallow-water propagation paths are classified as direct path and surface duct.

Direct Path

Direct path is the simplest mode. Direct path sound propagation occurs where there is an approximate straight-line path between the sound source and the receiver, with no reflection from any other source and only one change of direction due to refraction.

Surface Duct

A surface duct is simply a near-surface layer that traps sound energy. Surface ducts exist in the ocean if the following conditions are met:

1. The temperature increases with depth.

2. An isothermal layer is near the surface

In condition 1, sound velocity increases as the temperature increases. In condition 2, there is no temperature or salinity gradient; however, the in-crease in pressure with depth causes the sound velocity to increase with depth.

The greater the depth of a duct, the greater the difference between the surface velocity and the velocity at depth. There are also a greater number of sound rays trapped in the duct. Of course, the efficiency of a surface duct in transporting sound is dependent also upon the smoothness of the sea surface.

ENVIRONMENTAL CONTROLS

The success of active sonar searches in shallow water depends a great deal on environmental factors. Temperature gradients, horizontal as well as vertical; water depth; and the physical characteristics of the sea surface and bottom all impact shallow-water transmissions. Of these controls, water depth is the most important. Water depth determines the range and angle at which sound rays strike the bottom (angle of incidence) and to some extent the types of transmission paths that occur. Variations in the vertical temperature gradient, which result in sound speed variations, are of ut-most importance where sound is propagated through a surface duct. A change in gradient of .2°C per 30 meters can be the difference between an excellent duct with good ranges and no duct and poor ranges.

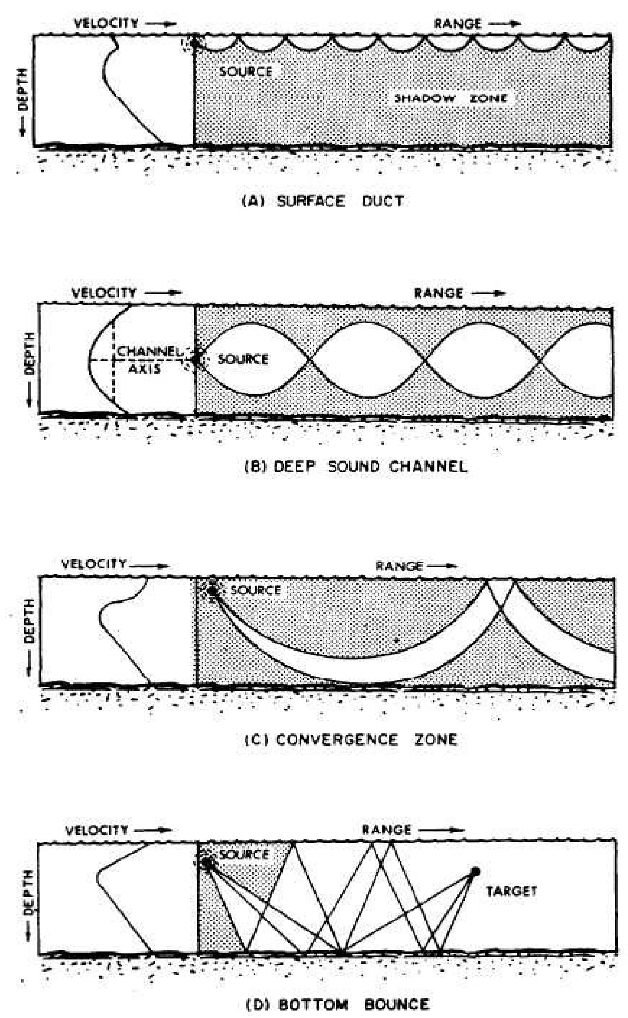
Horizontal velocity gradients in the ocean are not as great as those in the vertical; however, they can completely destroy a duct if they occur between the sound source and the target. Bottom composition and roughness control, to a large extent, the reflective and absorbent capabilities of the bottom. Shallow-water sediments are quite diverse. Areas of mud, sand, mud-sand, gravel, rock, and coral

In shallow water, as in deep water, the sound velocity profile controls the degree of refraction of sound rays. For an example of how similar profiles effect shallow- and deep-water transmissions, consider the following:

In deep water, where a strong negative gradient exists, sound rays are refracted downward and result in shadow zones. On the other hand, in shallow water the downward refracted rays bounce off the bottom, travel up-ward, and bounce off the sea surface. This process continues until the shadow zone is completely insonified. Consequently, this results in better detection probability.

DEEP-WATER TRANSMISSIONS

In deep water, sound may travel from and to a sonar via surface duct, convergence zone, bottom bounce, and sound channel tr



Surface Ducts

Surface ducts occur in deep water just as they do in shallow water

Sound Channels

A sound channel is formed when a negative-velocity gradient overlies a positive-velocity gradient. The thermal gradient necessary to produce a sound channel is negative over isothermal or negative over positive. The sound channel axis is found at the point of sound-velocity gradient change. The axis is the point of minimum sound speed. Sound channels trap sound rays and provide extremely long ranges. Such thermal conditions are found in shallow and deep water.

Shallow sound channels are found in the near-surface layer. They are rare and transitory (they move), and occur when thermal conditions are unstable (cold water over warm). In the Pacific Ocean, shallow sound channels are most common in the area north of 40°N between Hawaii and the continental United States. In the Atlantic, they are most frequently observed in the vicinity of the Gulf Stream.

Deep sound channels are far more prevalent than their shallow counterpart. In the deep ocean, temperature generally decreases with depth (the main thermocline). This produces a negative-velocity gradient and sound rays that refract downward.

In the Atlantic, such gradients exist to a depth of approximately 700 fathoms. Below 700 fathoms, the gradient becomes isothermal. In the Pacific, the isothermal layer begins around 500 fathoms. Below these depths, the greater pressure combines with the isothermal-temperature gradient to produce a positive-velocity gradient. The sound rays are refracted upward.

The depth of the gradient change is known as the deep-sound-channel axis. The deep-sound-channel axis varies from 1,225 meters in the mid-latitudes to near the surface in the polar regions. Extremely long sonar ranges (on the order of thousands of miles) are possible within a deep sound channel. Deep sound channels are also

Convergence Zone

This sound transmission path is based on the principle that sound energy from a shallow source travels downward in the deep ocean and is refracted at depth. The refracted rays travel upward and reflect off the surface about 30 miles from the sound source. The reflected rays travel downward, and the pattern repeats itself. The sound rays reappear in the surface layer at successive intervals of about 30 miles out to several hundred miles.

There are two conditions necessary for convergence zone transmission: (1) The sound velocity at depth must be equal to or greater than the sound velocity at the surface and (2) the water depth below the deeper sound velocity maximum must be great enough to permit the refracted sound rays to converge in a small area at the surface.

The three transmission paths just discussed depend upon the restrictive conditions of the velocity profile and the depth of the sound source and receiver. Thus, if velocity gradients are ignored, path predictions are not possible. The fourth path can be predicted roughly without considering gradients. This path is the bottom

Bottom Bounce

Bottom bounce transmission uses angled ray paths to overcome velocity gradient changes. The sound energy is directed downward at an angle. With steeply inclined rays, transmission is relatively free from thermal effects at the surface, and the major part of the sound path is in nearly stable water. The sound energy is affected to a lesser degree by velocity changes than the more nearly horizontal ray paths of other transmission modes.

Long ranges can occur in water deeper than 1,000 fathoms, depending on the bottom slope. It is estimated that 85% of the ocean is deeper than 1,000 fathoms, and bottom slopes are generally less than or equal to 1 degree. On this basis, relatively steep angles can be used for single bottom reflection to a range of approximately 20,000 yards. At shallower depths, multiple bounce paths develop which produce scattering and its high intensity energy loss.

Learning Objective:

Define and differentiate between the elements used in the active and passive sonar equations.

Active Sonar Equation

In determining ranges of active sonar transmissions, scientists use mathematical equations. The active sonar equation takes two forms: Active sonar performance may be noise- or reverberation-limited, depending on the dominant type of background interference. When the dominant background is self noise, the active sonar equation

$$SE = SL + TS - RD - NL + DI - 2\,PL,$$

where SE = Signal or echo excess

SL = Source level

TS = Target strength

RD = Recognition differential

NL = Noise level

DI = Directivity index

$2\,PL$ = Two-way propagation loss

When reverberation dominates, the equation may be written

$$SE = SL + TS - RD - RL - 2\,PL,$$

where SE = Signal excess
SL = Source level
TS = Target strength
RD = Recognition differential
RL = Reverberation level
2 PL = Two-way propagation loss

SIGNAL EXCESS

Signal excess is the amount of sound energy received from a target over and above the amount required to detect it. Signal excess is based on probability conditions. When the signal excess is zero, the probability of target detection is considered to be roughly 50%. Signal excess, like all of the other factors of

SOURCE LEVEL

Source level of the sonar projector pertains to the intensity of the radiated sound, in decibels, relative to a reference intensity. Source level is controlled by the design, maintenance, and mode of operation of a sonar.

RECOGNITION DIFFERENTIAL

Recognition differential pertains to a sonarman’s ability to differentiate target noise from background noise. It is a function of target design, maintenance, and a target’s mode of operation. Recognition differential was originally defined as the signal-to-background-noise ratio required at the receiver to recognize a target 50% of the time. However, using the 50% probability resulted in too many signals being classified as targets that were not targets. The inordinate amount of false alarms led to a more specific qualification of RD. Today, RD can apply to a

TARGET STRENGTH

The target strength of a reflecting object is the amount by which the apparent intensity of sound scattered by the object exceeds the intensity of the incident sound. This value depends on the size, shape, construction, type of material, roughness, and aspect of a target, as well as the angle, frequency, and waveform of the incident sound energy.

NOISE LEVEL

Noise level pertains to ambient noise and self-made noise at the location of the sonar. Noise level is a function of the environment and ship's speed.

PROPAGATION LOSS

Propagation loss is the loss of signal strength (intensity) between the sonar and the target. In the active sonar equation, PL is a two-way loss of energy, since sound energy travels out from the transmitter and back to the receiver. Propagation loss in water depends on the following factors:

1. Spreading of the sound wave front. The farther the sound wave moves from the source, the greater the size of the wave front and the spreading of the sound energy.

2. Conversion of the mechanical energy in a sound wave to heat (attenuation).

3. Scattering due to surface, bottom, and suspended particulate reflections.

4. Leakage of sound energy from layers of trapped sound (ducts and sound channels) and leakage of energy into areas where it is absorbed and is not capable of target detection (shadow zones) is known as diffraction loss. Velocity gradients that result in ducts

DIRECTIVITY INDEX

Directivity is a function of the dimensions of a sonar's hydrophore (receiver) array, the number and spacing of the hydrophores, and the frequency of the received acoustic energy. These functions enable the direction of a received signal to be determined. Directivity also reduces noise arriving from directions other than that of the target. The directivity index pertains to a sonar's ability to discriminate against noise. It is defined as the signal-to-noise ratio (in decibels) at the terminals of a hydrophore array or a directional hydrophore, relative to the signal-to-noise ratio of a nondirectional hydro-phone. Thus defined, DI is always a positive quantity in the equation.

NOTE

DI is not included in the reverberation-limited equation, because hydrophore directivity cannot distinguish against reverberations.

REVERBERATION LEVEL

Reverberation is observed at the sonar receiver. The level of reverberation is a function of source level; range; and surface, volume, and bottom reverberation. When an active sonar is reverberation limited, RL is used in the equation in place of NL and DI.

Passive Sonar Equation

In passive-sonar operations, the hydrophores pick up sounds generated by a multitude of sound sources. Sonarmen must differentiate between sounds generated by a target and interfering background noise. This process is best described in what is known as the passive sonar equation. The passive form of the sonar equation, like the active form, is written using several different symbols to repr… …ters. One form of the equation …

$$SE = SL - RD - NL + DI - PL,$$

where SE = Signal excess

SL = Source level

RD = Recognition differential

NL = Noise level

DI = Directivity index

PL = Propagation loss

SIGNAL EXCESS

Signal excess has the same meaning in the passive equation that it does in the active equation.

SOURCE LEVEL

Source level pertains to target-radiated noise. It is the amount of sound energy generated by a target. The level of energy reaching the sonar receiver depends on the type of target and its mode of operation. Source level is a function of frequency, speed, depth, and target aspect. The latter refers to a target’s orientation in relation to the sonar receiver.

RECOGNITION DIFFERENTIAL

RD has the same meaning as in the active sonar equation.

NOISE LEVEL

The definition for NL in the passive equation is the same as in the active equation. Passive sonars may be ambient-noise or self-noise limited. These sonars lessen the noise in certain frequency ranges, thereby permitting a target signal to be more readily detected.

Ambient Noise. —Ambient noise is that part of the total background noise created by surface-ship traffic, wave action, precipitation, ice, and certain forms of marine life.

Self Noise. —Self noise is that part of the total background noise attributable to the sonar equipment, the platform on which it is mounted, or the noise caused by the motion of the platform. The major classes of self-noise are machinery noise, propeller noise, and hydrodynamic noise. The latter

DIRECTIVITY INDEX

DI has the same meaning as in the active sonar equation.

PROPAGATION LOSS

PL has the same meaning as in the active sonar equation except that with passive sonar, the energy loss is one-way.

References

Fleet Oceanographic and Acoustic Reference Manual, RP-33.

Operational Oceanography Module II, Acoustics and Sound Ray